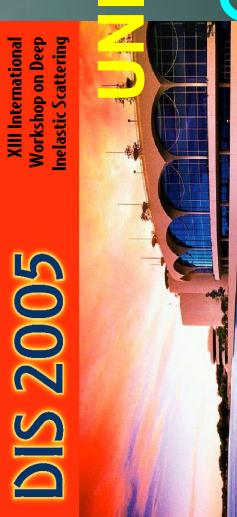




Top Quark Production Cross-Section at the Tevatron Collider

XIII International
Workshop on Deep
Inelastic Scattering



DIS 2005

KIRTI RANJAN

UNIVERSITY OF DELHI, INDIA & FERMILAB
On behalf of DØ & CDF Collaboration

27 April – 1 May 2005, Madison, Wisconsin, USA



OVERVIEW

- ↳ Motivation
- ↳ Tevatron Run II & Detectors
- ↳ Top quark production & decay
- ↳ Results

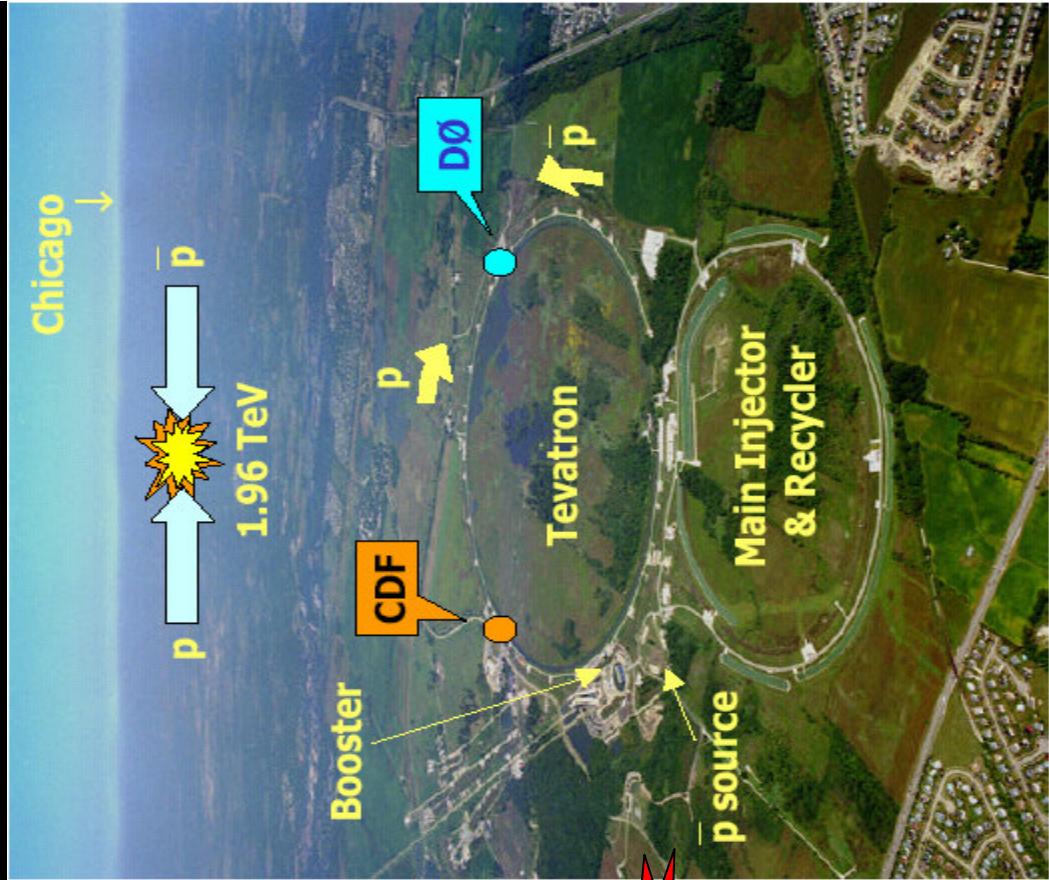
► Top pair production



- Dilepton
- lepton + Jet **NEW**
- All Jets

► Single top production

- ↳ Summary





MOTIVATION

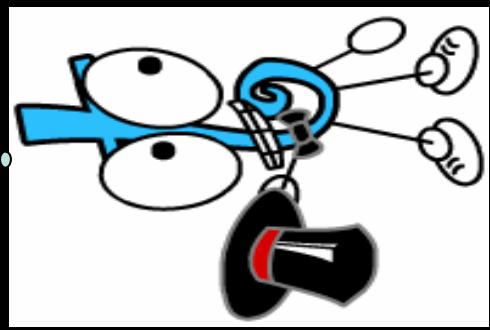


- ☛ Discovered by DØ & CDF in 1995
 - ⇒ Studied with limited Run I statistics!

It's FUN
studying
TOP!

- ☛ Role in the Standard Model (SM)

- ⇒ $m_{top} \sim 175$ GeV : Heaviest elementary particle
 - Top quark mass ~ EWSB scale
 - ⇒ Short lifetime ($\sim 10^{-24}$ s) – properties of bare quark
 - ⇒ Accurate measurement of top mass constrains Higgs mass



- ☛ Sensitive to physics beyond the SM

- ⇒ Look for non-SM production or decay modes

- ☛ Possible background for New Physics searches

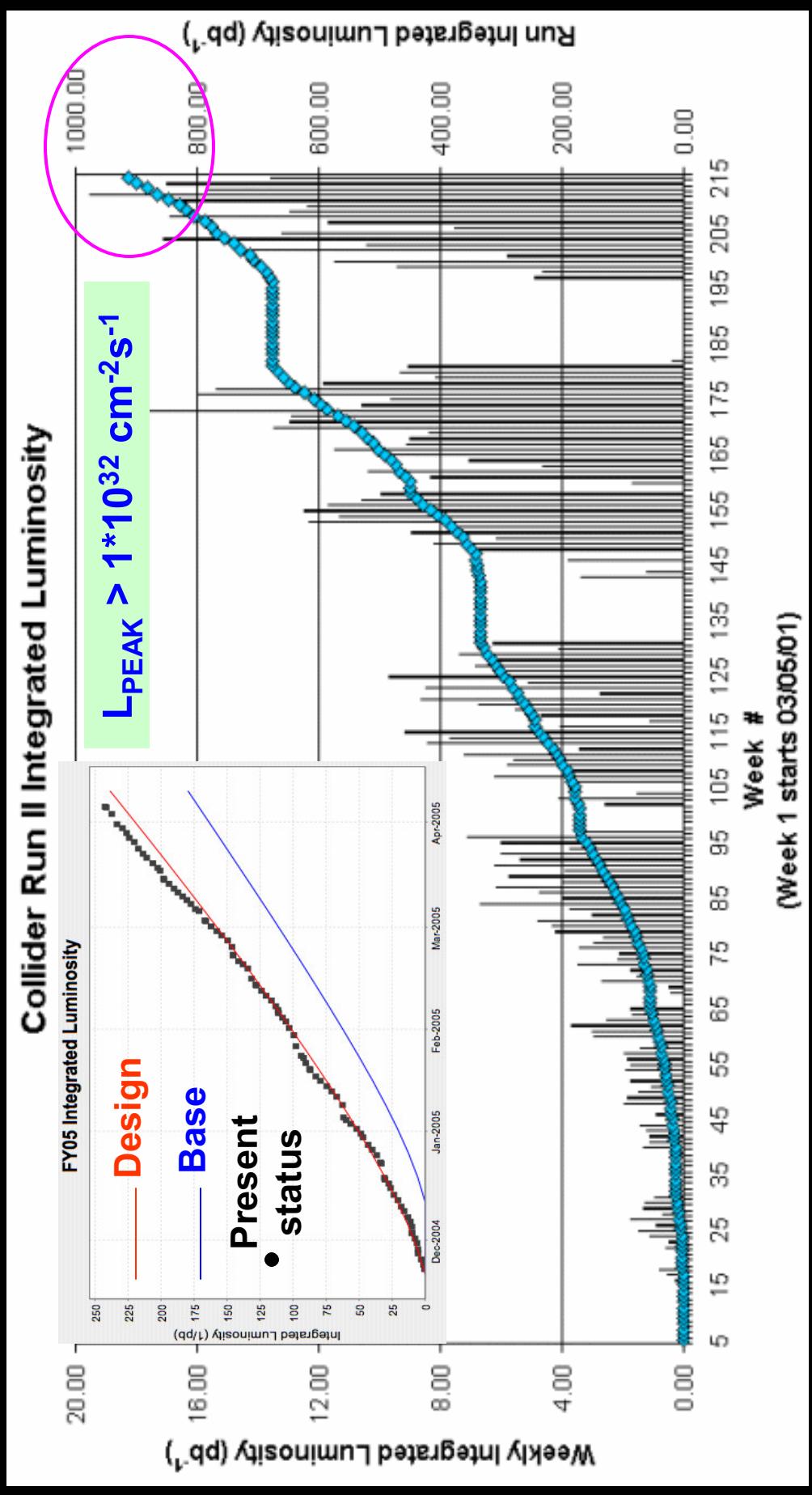
TEVATRON is THE only TOP FACTORY till LHC starts operating



TEVATRON RUN II



- ☺ Tevatron is performing extremely well !
- ☺ Both experiments have accumulated $\sim 680 \text{ pb}^{-1}$ of Data
- ☺ Results presented here $\sim 150 - 350 \text{ pb}^{-1}$





DETECTORS



Muon system

Hadronic

Tracker

EM

Muon system

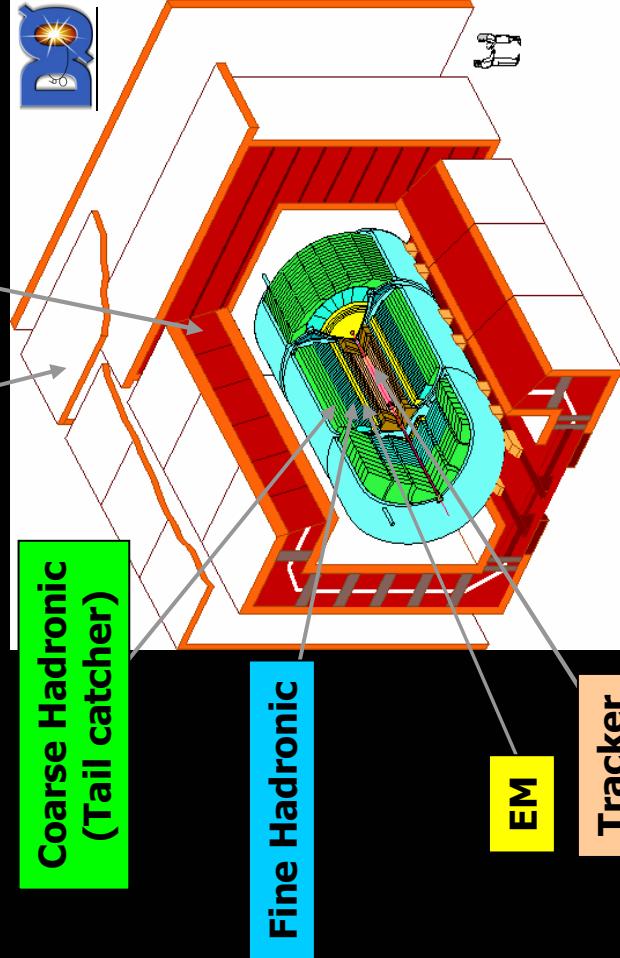
Magnetized iron

Coarse Hadronic
(Tail catcher)

Fine Hadronic

EM

Tracker



- New Silicon Detector and Central Fiber Tracker in a 2T solenoid
- Substantially upgraded muon system
- Faster DAQ

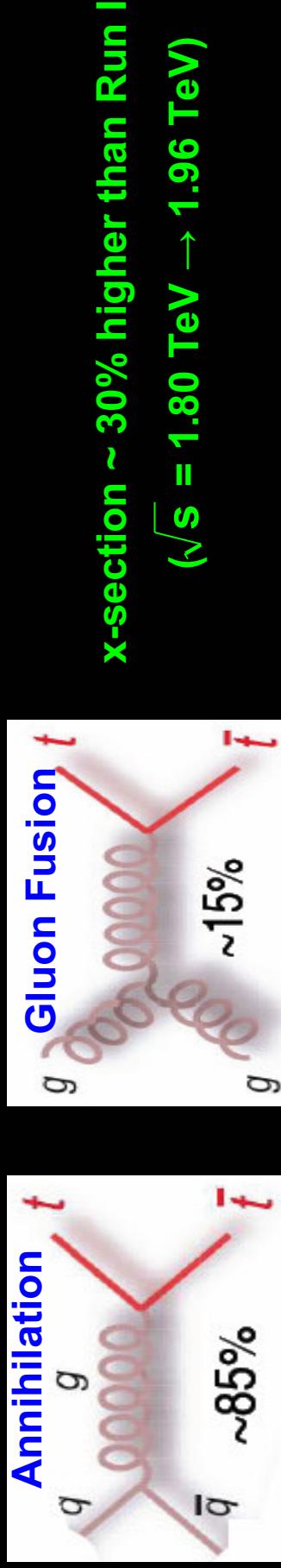
- New Silicon Detector
- New Central Drift Chamber
- New End Plug Calorimetry
- Extended muon coverage
- Faster DAQ



TOP QUARK PAIR PRODUCTION & DECAY

- Strong Production

⇒ At Tevatron energies ($\sqrt{s} = 1.96 \text{ TeV}$) : primarily produced in $t\bar{t}$ pairs



Role reversed at LHC!

SM Prediction (at $m_{top} = 175 \text{ GeV}$)

$$\sigma(t\bar{t}) = 6.7^{+0.7}_{-0.9} \text{ pb}$$

(Cacciari et. al., JHEP 0404:068, 2004)

Dominant Uncertainties: PDF(7%) & Scales (5%)

- In SM, $\text{BR}(t \rightarrow W b) \sim 100\%$

- Final states are determined by W decay modes

RUN I ($\sqrt{s} = 1.8 \text{ TeV}$) Results

$$\text{CDF: } \sigma(t\bar{t}) = 6.5^{+1.7}_{-1.4} \text{ pb}$$

$$\text{D\O: } \sigma(t\bar{t}) = 5.7 \pm 1.7 \text{ pb}$$



$t\bar{t}$ FINAL STATES



DILEPTON

[ee, $\mu\mu$, e μ , + 2 b jets]

- Small BR ~ 5%
- Smallest background
- Large BR ~ 30%
- Moderate background

LEPTON+JETS

[e, μ + 4 jets (2 b jets)]

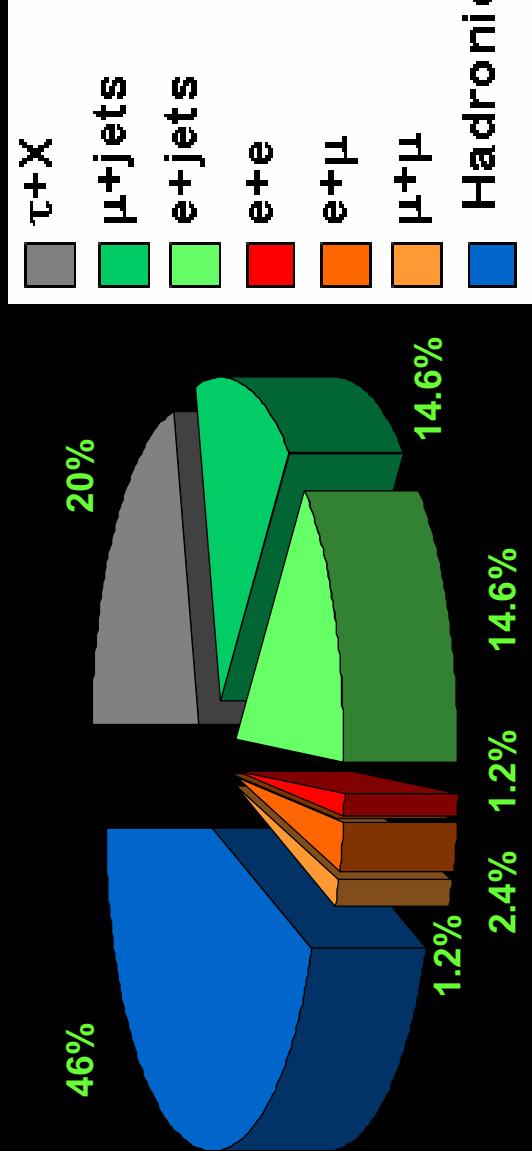
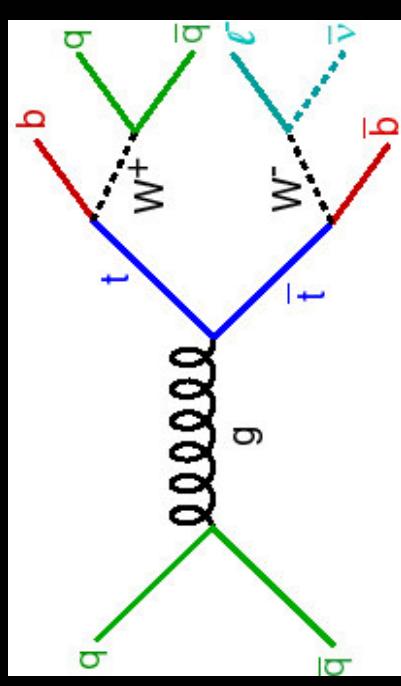
- Largest BR ~ 46%
- Largest background

Golden Mode

[6 jets (2 b jets)]

- Largest BR ~ 46%
- Largest background

ALL HADRONIC



Requires good identification of e , μ , jets, & Missing E_T



DILEPTON

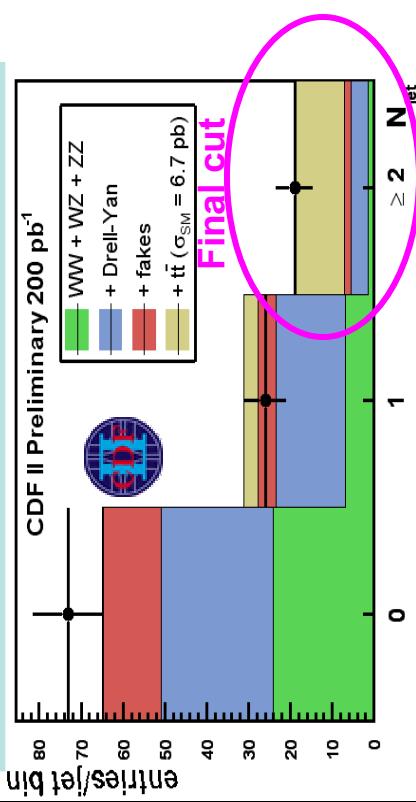
Signal Selection :

- Two high P_T Leptons
- Two high P_T Jets
- Large E_T^{miss}

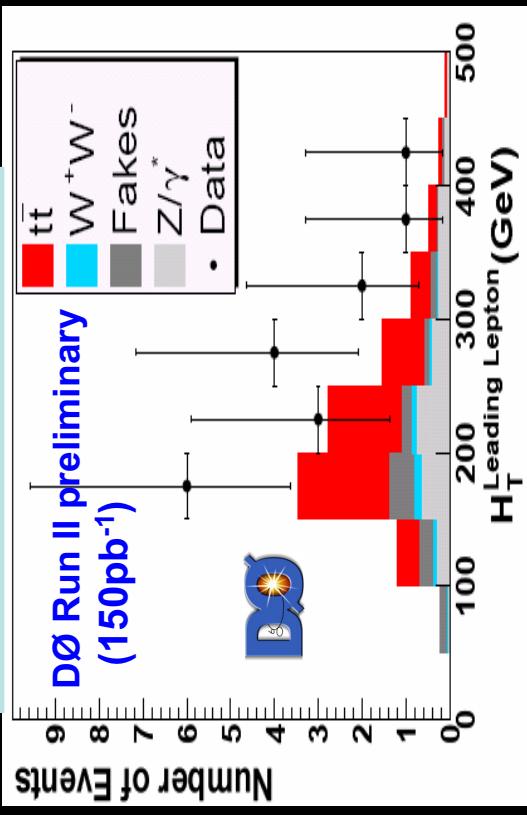
Background :

- Physics (from MC):
 $Z/\gamma^* \rightarrow \tau\tau$, Dibosons
- Instrumental (from Data):
fake E_T^{miss} , fake Leptons

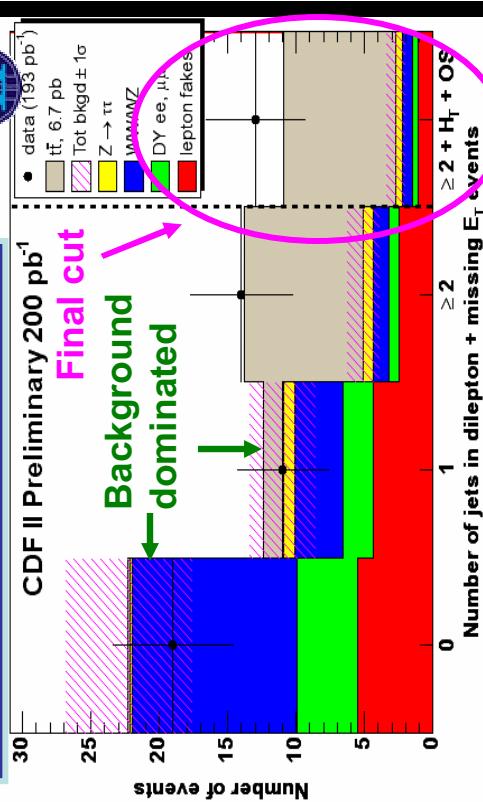
One lepton & One oppositely charged track



Two Oppositely charged leptons



Two Oppositely charged leptons



$$D\emptyset : 150 \text{ pb}^{-1} \quad \sigma = 14.3^{+5.1}_{-4.3} \text{ (stat)}^{+2.6}_{-1.9} \text{ (syst)} \pm 0.9 \text{ (lumi)} \text{ pb}$$

$$\text{CDF: } 200 \text{ pb}^{-1} \quad \sigma = 7.0^{+2.4}_{-2.1} \text{ (stat)}^{+1.7}_{-1.2} \text{ (syst + lumi)} \text{ pb} \quad (\text{PRL 93, 142001, 2004})$$

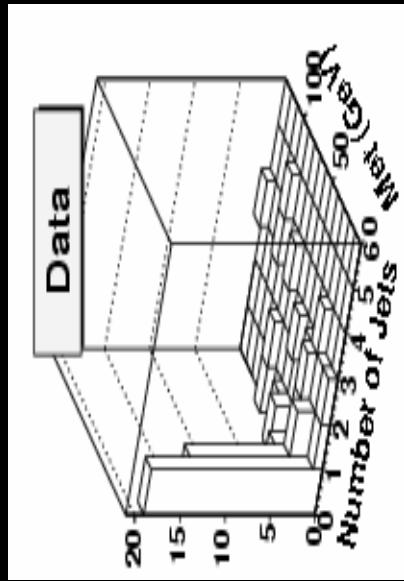
KIRTI RANJAN

DIS, Madison, Wisconsin, April 28, 2005

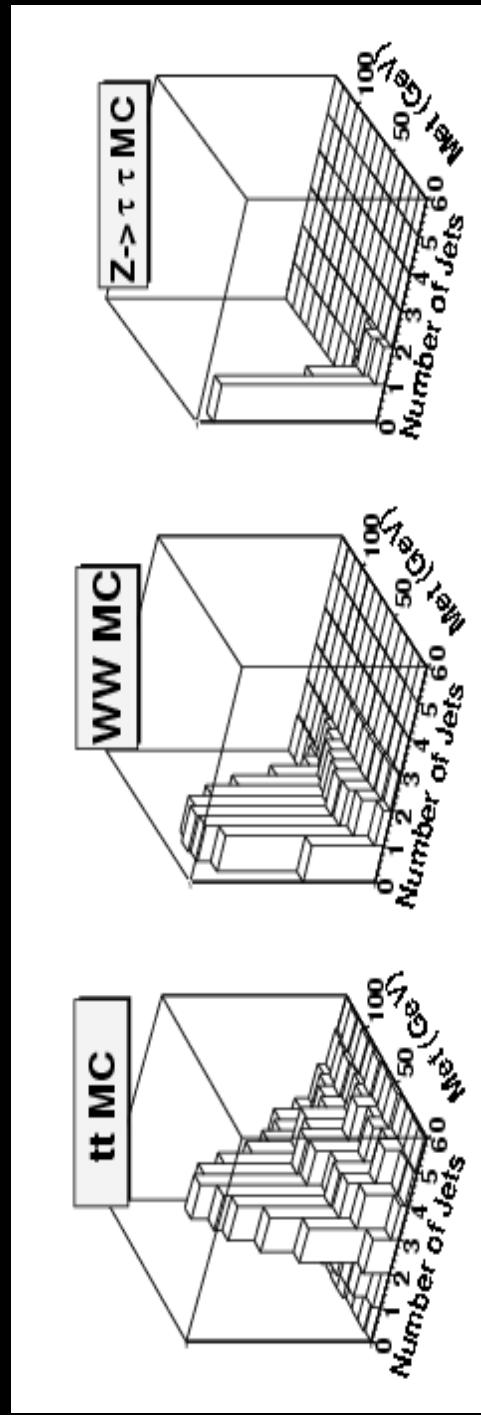


DILEPTON

- CDF : Loose cuts to increase no. of signal events
 - ⇒ Fit N_{jet} vs. E_T^{miss} distributions for physics backgrounds



CDF Preliminary
200 pb⁻¹



$$\text{CDF: } 200 \text{ pb}^{-1} \quad \sigma = 8.6^{+2.5}_{-2.4} \pm 1.1 \text{ pb}$$



LEPTON + JETS (TOPOLOGICAL)

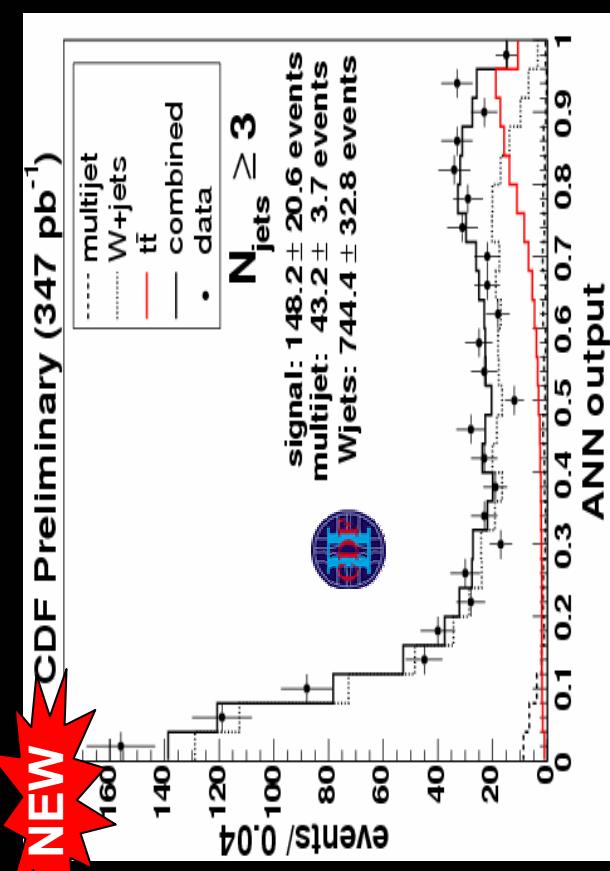
Signal selection

- One high P_T Lepton
- Multiple high P_T Jets
- Large E_T^{miss}

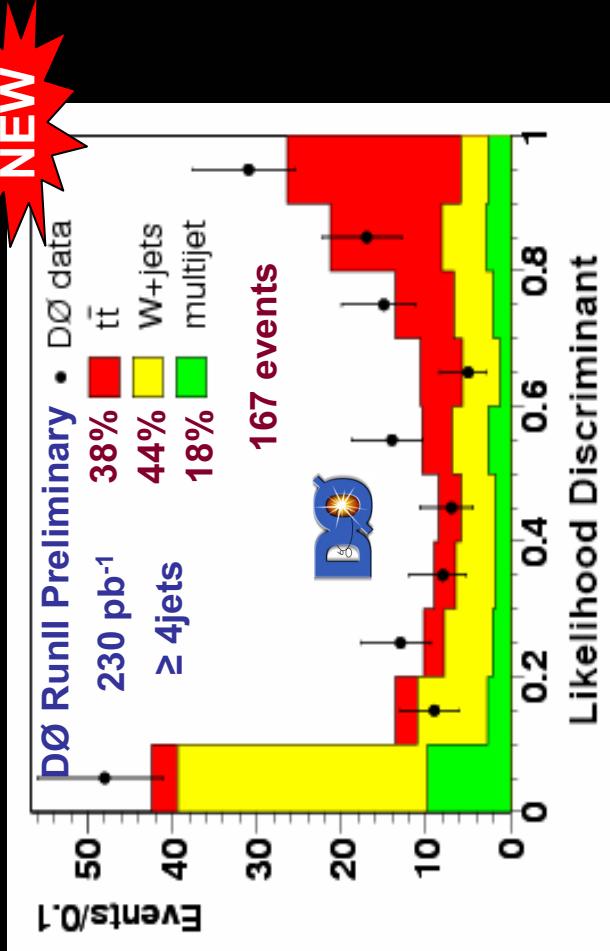
Backgrounds

- Physics : W+Jets
- Instrumental:
QCD Multijet
- ≥ 4 jets

• Strategy : Extract signal from kinematic / topological characteristics of the events
& use Neural Net (CDF) / construct Likelihood discriminant ($D\varnothing$)



NEW



NEW

$D\varnothing : 230 \text{ pb}^{-1} : \sigma = 6.7_{-1.3}^{+1.4} (\text{stat})_{-1.1}^{+1.6} (\text{syst}) \pm 0.4 (\text{lumi}) \text{ pb}$ (hep-ex / 0504043)

$\text{CDF: } 347 \text{ pb}^{-1} : \sigma = 6.0 \pm 0.8 (\text{stat}) \pm 1.0 (\text{syst}) \text{ pb}$



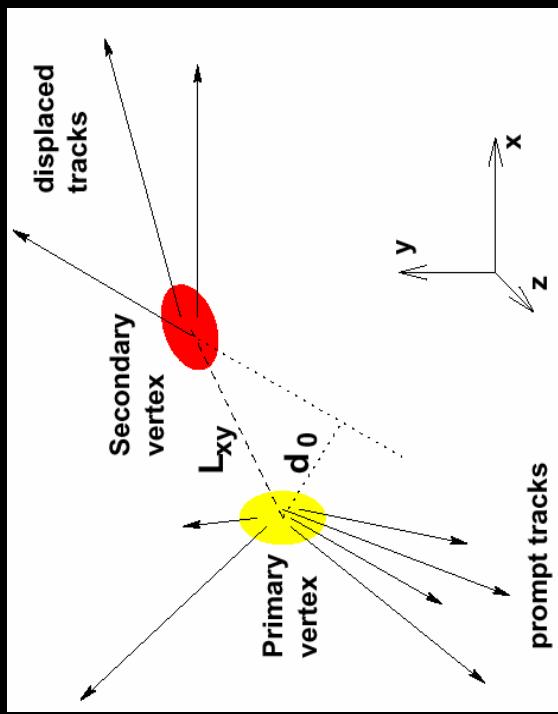
'b' JET IDENTIFICATION

- b-jets provide extra handle to identify Top quark

B Mesons are Massive & long-lived

(Lifetime Tagging)

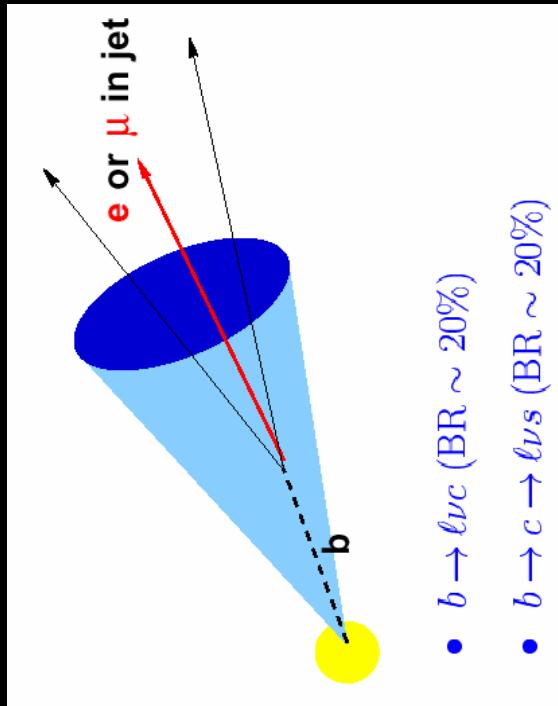
- Displaced track vertices : SVT (D \emptyset)
SVX (CDF)



Semi-leptonic decay of B-Mesons

(Soft Lepton Tag or SLT)

- Identify low- p_T e / μ inside jet



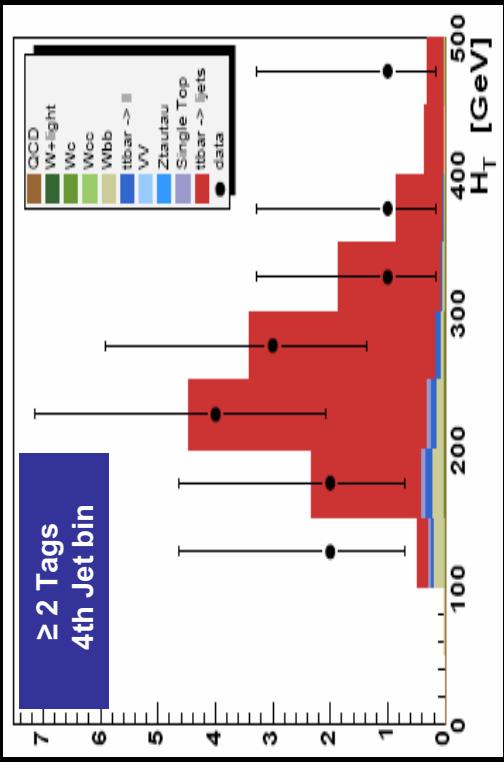
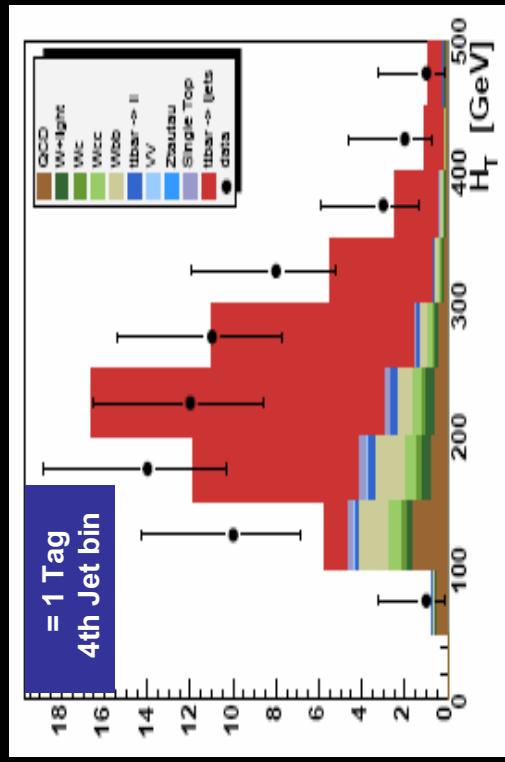
- $b \rightarrow \ell \nu c$ ($BR \sim 20\%$)
- $b \rightarrow c \rightarrow \ell \nu s$ ($BR \sim 20\%$)

$\sim 60\%$	→	$t\bar{t}$ event tagging efficiency
$\sim 0.5\%$	→	Light-flavor jet mistag rate



LEPTON + JETS (b-TAGGING)

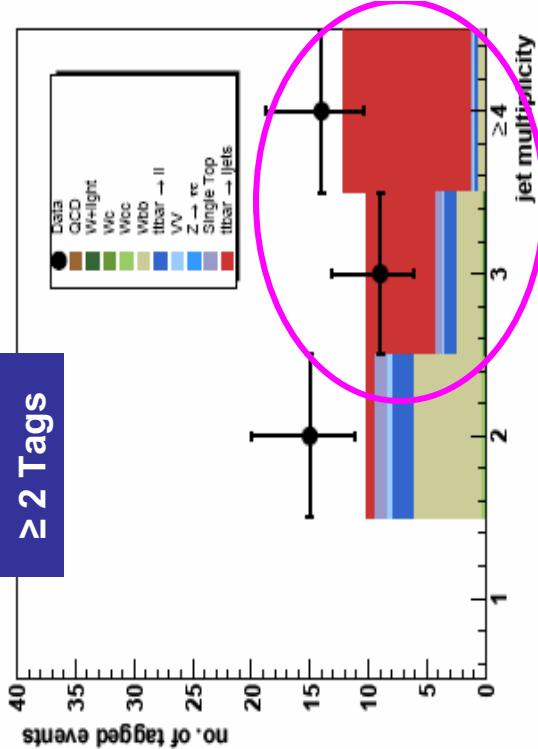
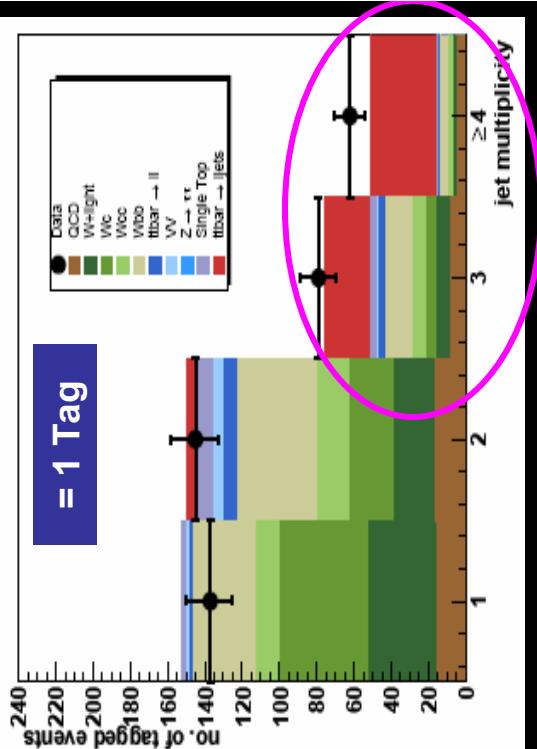
• D \emptyset : SVT Analysis



= 1 Tag

≥ 2 Tags

NEW



≥ 4

$$D\emptyset : 230 \text{ pb}^{-1} : \text{SVT} : \sigma = 8.6_{-1.1}^{+1.6} (\text{stat}) +_{-1.0}^{+1.1} (\text{syst}) \pm 0.6 (\text{lumi}) \text{ pb}$$

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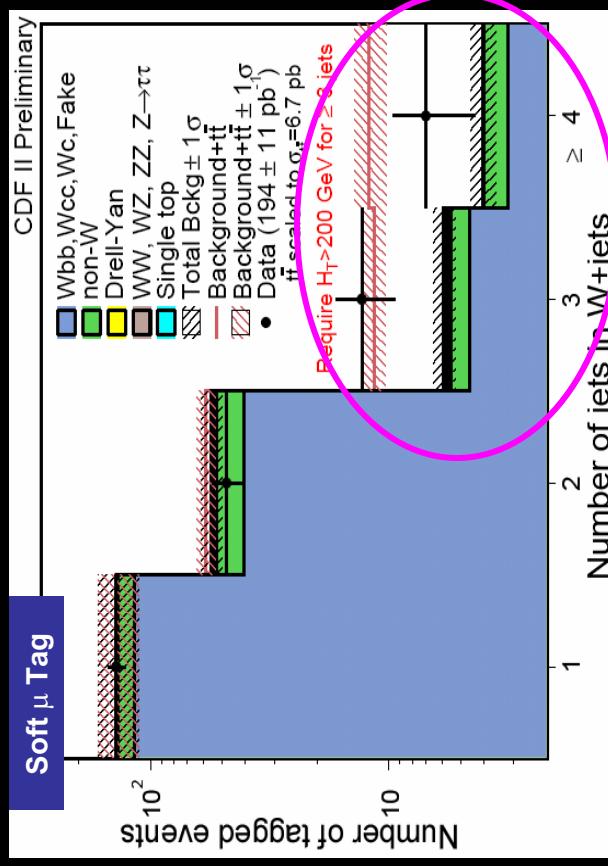
DIS, Madison, Wisconsin, April 28, 2005

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LEPTON + JETS (b-TAGGING)

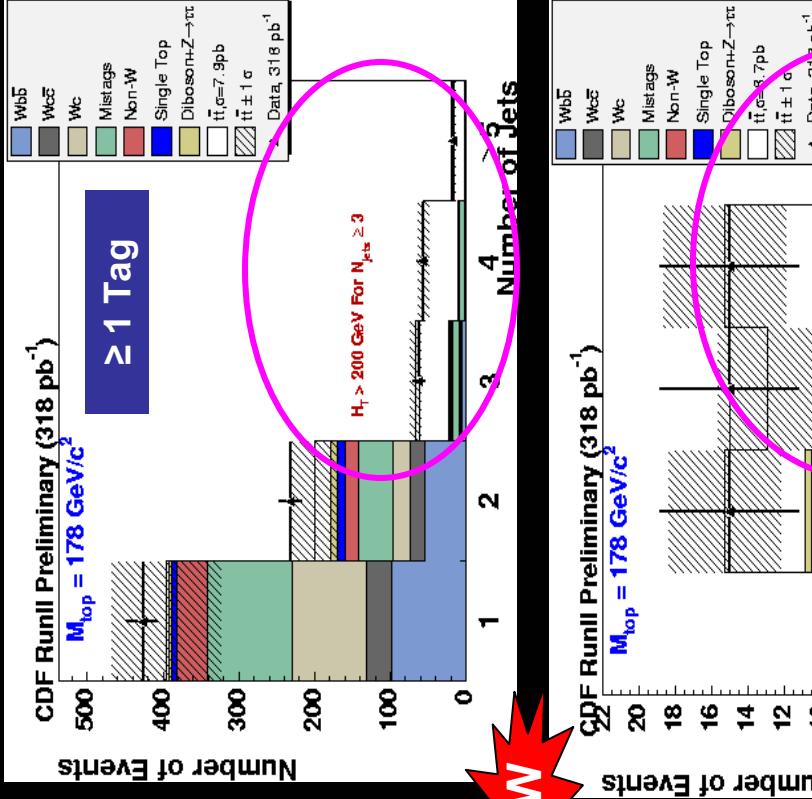
• CDF: Soft μ Tag & SVX Tagging



CDF : 194 pb⁻¹ : Soft μ Tag :
 $\sigma = 5.2^{+2.9}_{-1.9}(\text{stat})^{+1.3}_{-1.0}(\text{syst}) \text{ pb}$



CDF : 318 pb⁻¹ : Single Tag : $\sigma = 7.9 \pm 0.9(\text{stat}) \pm 0.9(\text{syst}) \text{ pb}$
CDF : 318 pb⁻¹ : Double Tag : $\sigma = 8.7 \pm 1.7(\text{stat}) \pm 1.5(\text{syst}) \text{ pb}$





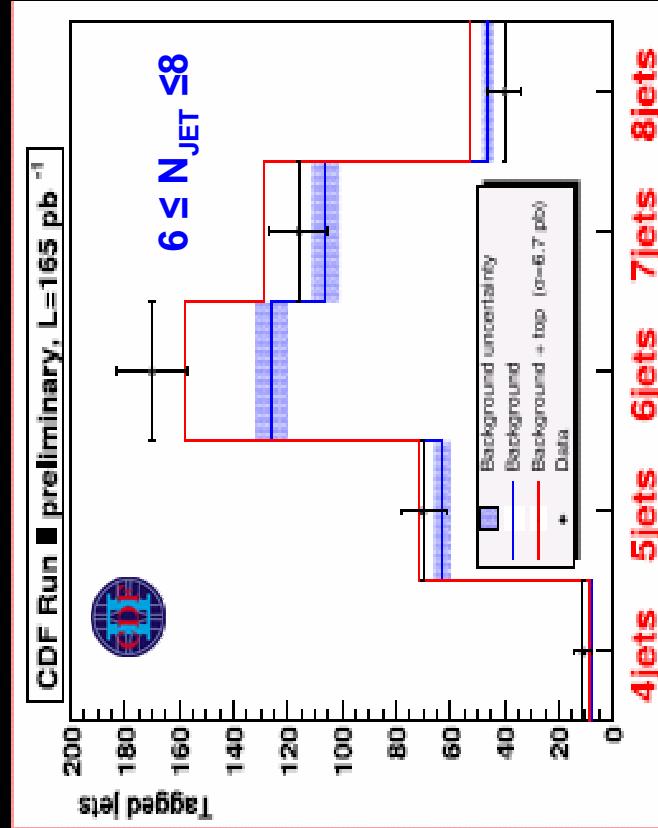
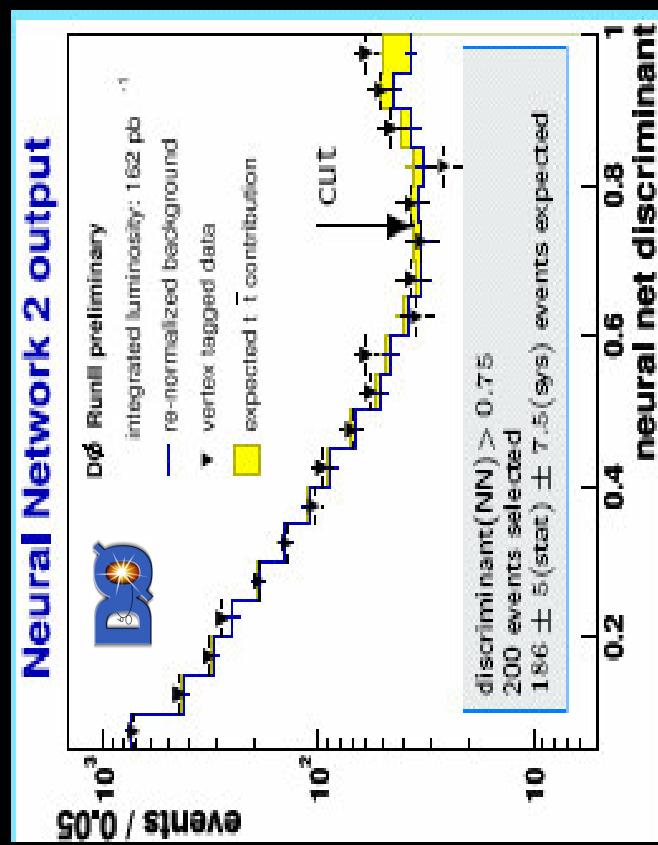
ALL HADRONIC

Signal selection

- Multiple (≥ 6) high P_T Jets
- Increase signal significance using both topological Cuts & b-tagging
 \Leftrightarrow small S/B $\sim 0.2 - 0.3$

Backgrounds

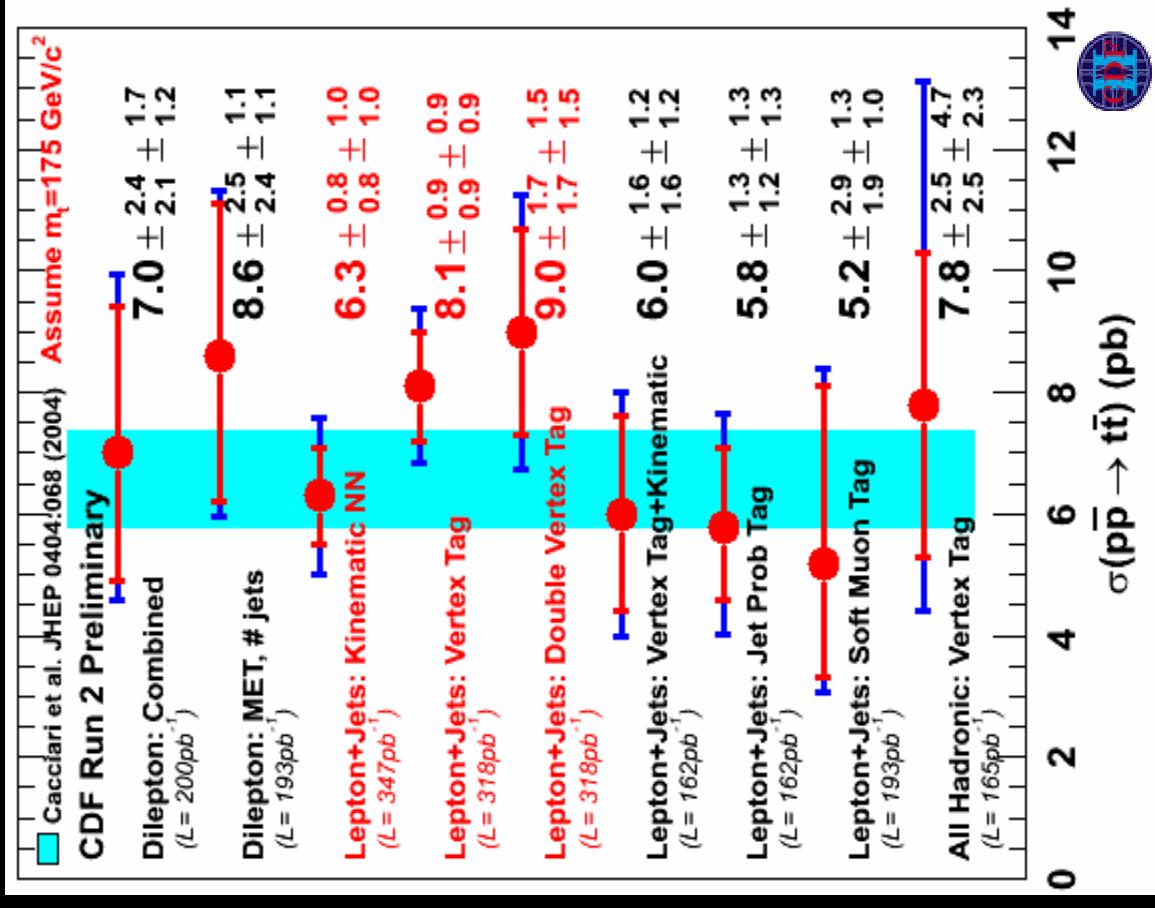
- Huge QCD multijet background
- Increase signal significance using both topological Cuts & b-tagging



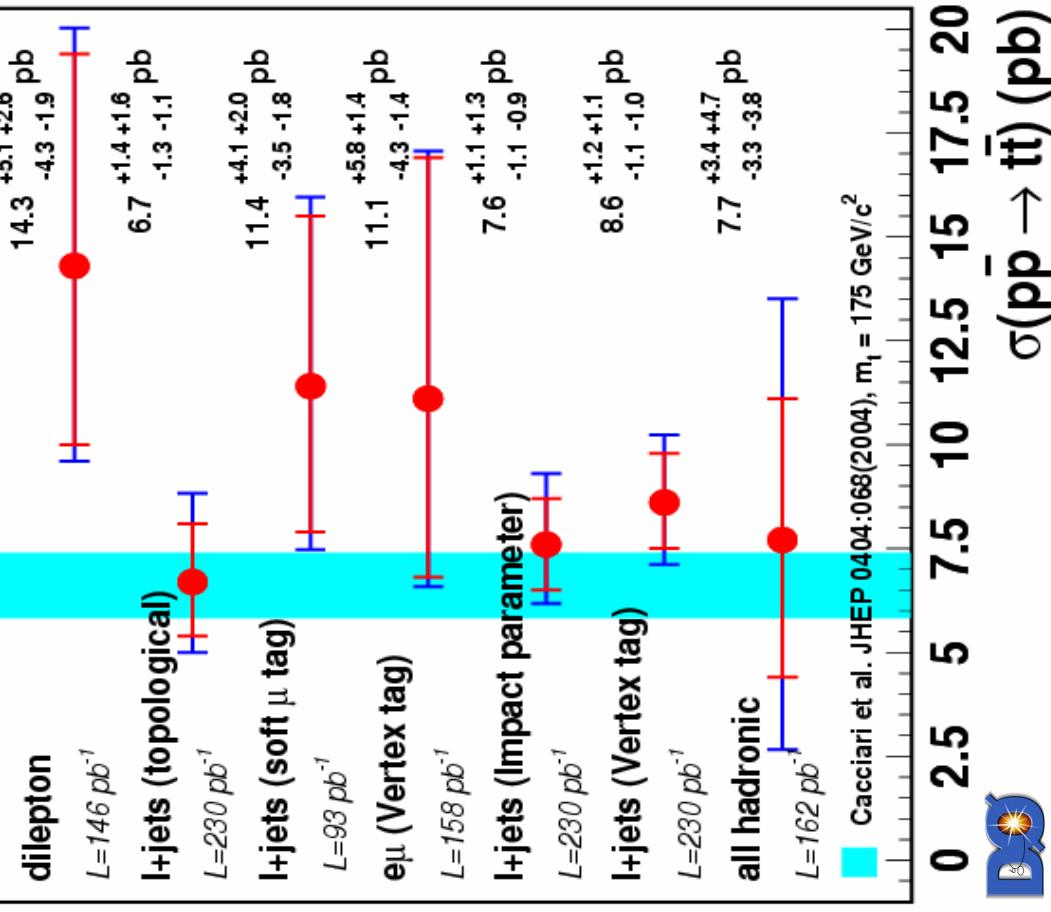
DØ : 160 pb⁻¹ : $\sigma = 7.7^{+3.4}_{-3.3} (\text{stat})^{+4.7}_{-3.8} (\text{syst}) \pm 0.5 (\text{lumi}) \text{ pb}$

CDF: 165 pb⁻¹ : $\sigma = 7.8 \pm 2.5 (\text{stat})^{+4.7}_{-2.3} (\text{syst}) \text{ pb}$

X-SECTION SUMMARY



DØ Run II Preliminary



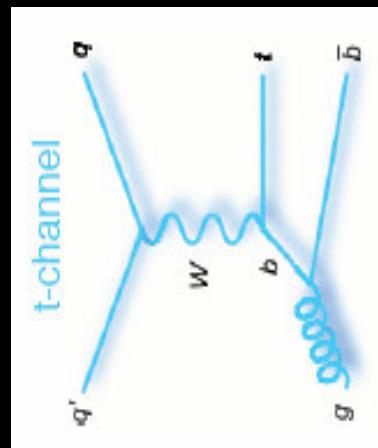
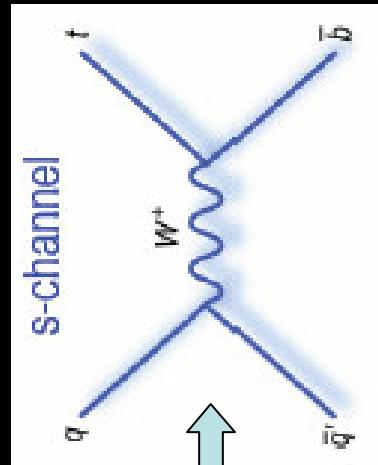


SINGLE TOP QUARK PRODUCTION



• Electroweak Production

- ⇒ Not yet observed !
- ⇒ Main production mechanisms
 - ⇒ ~ 40% of the $t\bar{t}$ x-section



• Signal Signature

- ⇒ Same as Lepton + Jets (≥ 1 b jet) but with lower jet multiplicity ⇒ Sensitive to leptonic decay of W (using Leptonic decay of W)
- ⇒ Direct measurement of $|V_{tb}|$
- ⇒ Sensitive to physics beyond the SM

• Background

- ⇒ $t\bar{t}$, W+jets, QCD multijets

SM Prediction : $\sigma_s \sim 0.88 \text{ pb}$, $\sigma_t \sim 1.98 \text{ pb}$
(Harris et al., PRD 66, 054024, 2002)
RUN I RESULTS ($\sim 100 \text{ pb}^{-1}$)
CDF: $\sigma_s < 18 \text{ pb}$, $\sigma_t < 13 \text{ pb}$, $\sigma_{st} < 14 \text{ pb}$
DØ : $\sigma_s < 17 \text{ pb}$, $\sigma_t < 22 \text{ pb}$

• Analysis Strategy

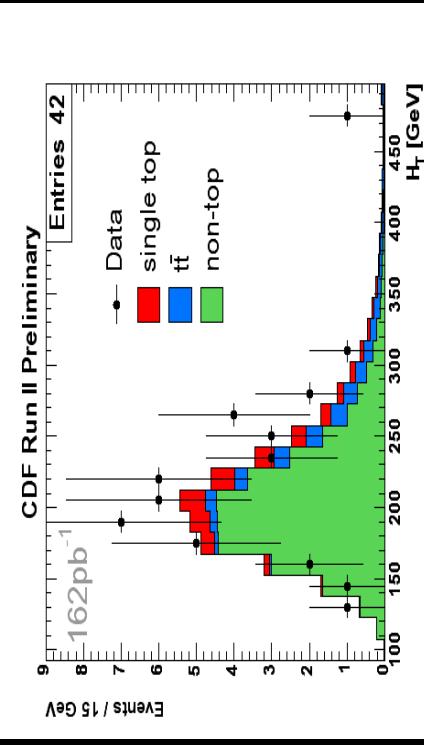
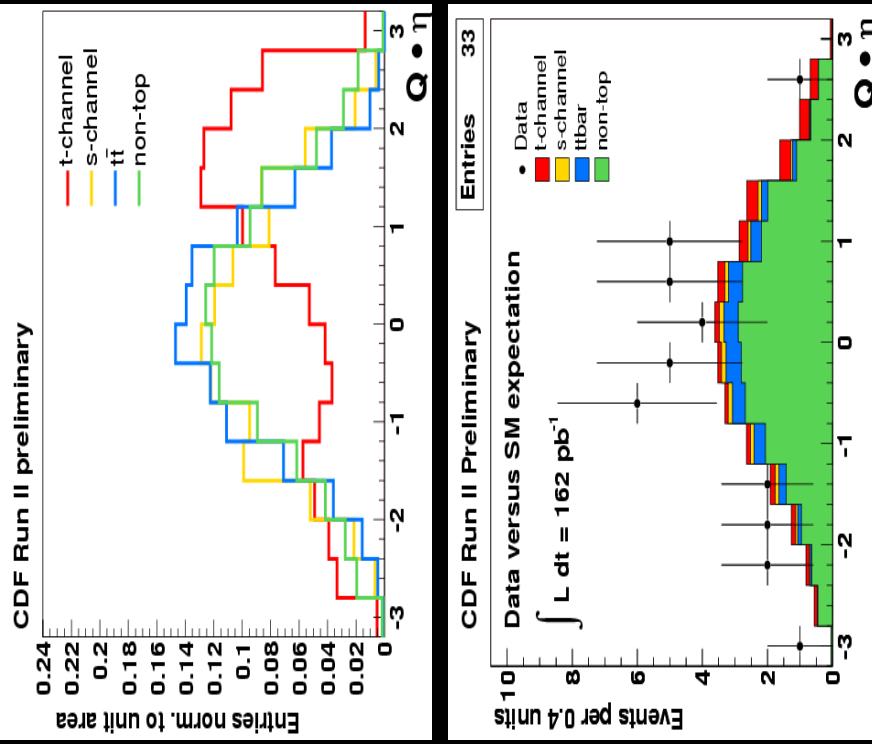
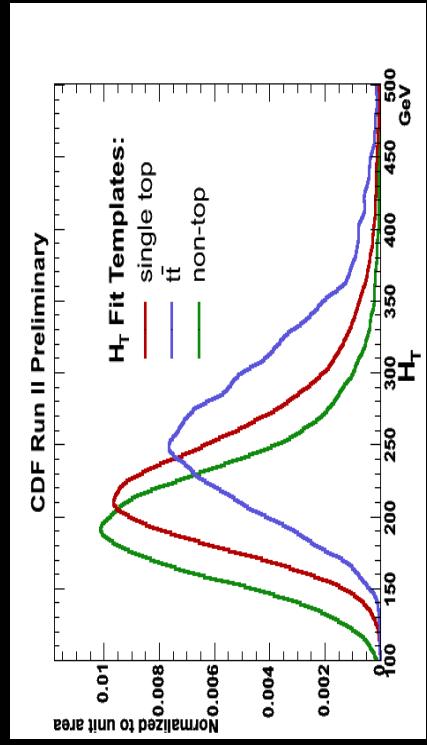
- ⇒ Maximize acceptance
- ⇒ Sophisticated methods to separate signal from background

SINGLE TOP QUARK PRODUCTION



**Combined : W+2jets (≥ 1 b jet);
 $140 \leq M_{h,b} \leq 210$ GeV**

**Channel specific : exactly 1 b-jet
(t-channel) or 2 b-jets (s-channel)**



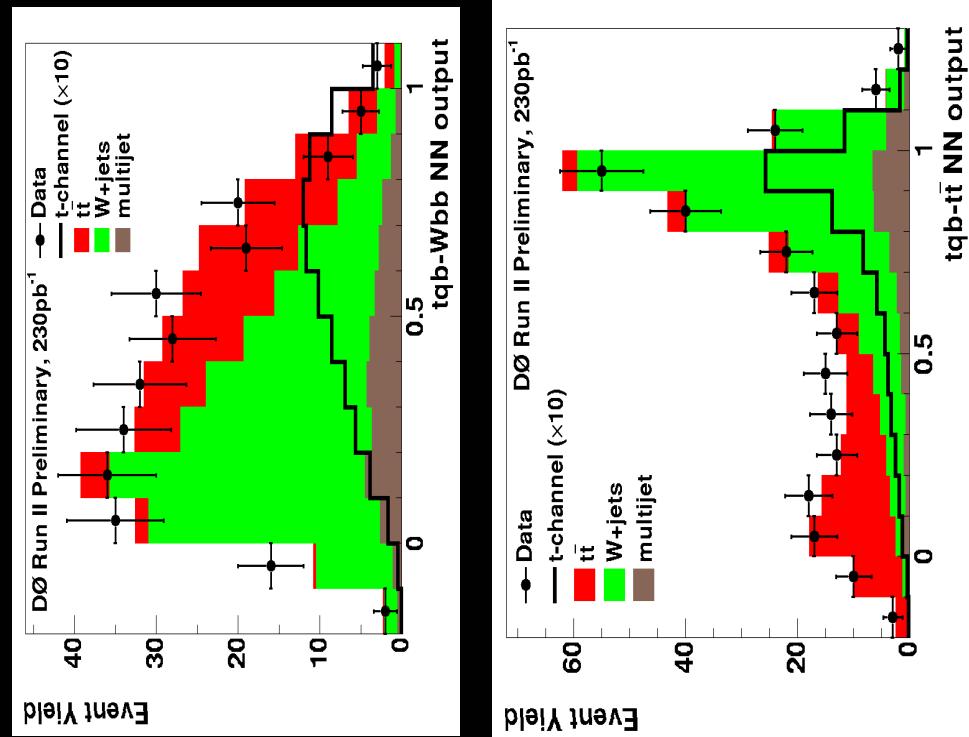
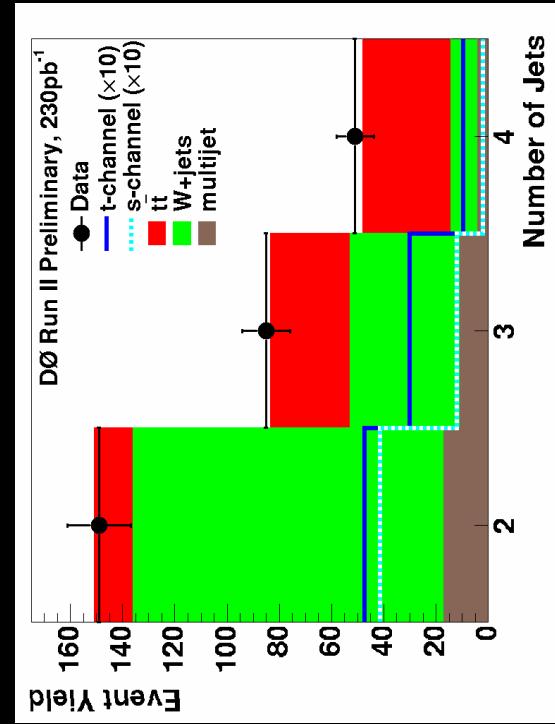
**162 pb^{-1}
@ 95% CL
(PRD 71, 012005, 2005)**

**$\sigma(s-t) < 17.8 \text{ pb}$
 $\sigma(s-\text{channel}) < 13.6 \text{ pb}$
 $\sigma(t-\text{channel}) < 10.1 \text{ pb}$**



SINGLE TOP QUARK PRODUCTION

- 👉 Separate signal from background
- $2 \leq N_{\text{JET}} \leq 4; \geq 1 \text{ b-jet}; \geq 1 \text{ non-}b \text{ jet in t-channel}$
- ⇒ Cut based → Event Counting
- ⇒ Decision Tree
- ⇒ Neural Network



230 pb⁻¹ Cut based $\sigma_t < 10.6 \text{ pb}$ NEW WORLD'S
 @ 95% CL Decision Tree $\sigma_t < 8.3 \text{ pb}$ BEST LIMIT:
 Neural Network $\sigma_t < 6.4 \text{ pb}$ $\sigma_t < 5.0 \text{ pb}$ improvement by
 a factor of ~2

NEW

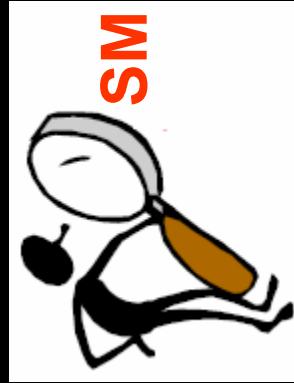
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DIS, Madison, Wisconsin, April 28, 2005



OUTLOOK

- ☛ Tevatron is performing remarkably well
- ☛ Top quark pair production
 - ⇒ Measurements in different channels providing consistent results with the SM
 - ⇒ b-tagging has provided a powerful handle to identify top quark
 - ⇒ With more data, x-section measurement is getting dominated by systematic uncertainties
 - Working very hard towards reducing systematics
- ☛ Single Top quark production
 - ⇒ New world's best limit on x-sections
 - ⇒ Observation expected with $\sim 1 - 2 \text{ fb}^{-1}$ of Data
 - Analyses refinement continues
- ☛ Analysis with more data is on the way



Top Quark: A Journey from Discovery → Precision has begun!